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MEASUREMENTS OF LOW ENERGY PROTONS ON THE SATELLITE "COSMOS-41" *

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SUMMARY

This paper brings forth the results of data processing on measurement of low energy protons by semiconductor "P - r" counters for the period from the end of August to the end of December 1964. It was found that the outer radiation belt constitutes a relatively steady formation and its outer part is the only one undergoing temporal variations, beginning with $L \geqslant 4.5$.- The identical altitude course and character of variations of low energy protons and hard electrons of the outer belt in $L \geqslant 5$, points to a common trapping and acceleration mechanism for both forms of radiation.- Taking into account the dependence of these variations on the geomagnetic setup, it may be assumed, that anomalous diffusion constitutes such a mechanism for particles in the Earth's magnetosphere at the expense of relatively weak nonstationary disturbances of the geomagnetic field, which are observed rather frequently.

* * *

The satellite "Cosmos-41" was launched on 22 August 1964 into an orbit of 39.855 km apogee and 394 km perigee, inclined to the equatorial plane at an angle of 65°. A radiometric apparatus was installed on board of Cosmos-41, designed to study the geomagnetically trapped radiation the constitution of which being shown in Table 1.

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* IZMERENIYA NIZKOENERGICHNYKH PROTONOV NA SPUTNIKE "KOSMOS-41".

TABLE 1

DETECTOR	SHIELDING	GEOMETRIC FACTOR	FORM AND ENERGY OF REGISTERED PARTICLES
Semiconductor "P-r" counter with a sensitive quartz layer 3 mg/cm^2	200 mkg/cm^2 Ag & Al	0.07 cm^2 sterad.	$0.4 \leqslant E_p \leqslant 7$ mev.
Identical counter	20 mg/cm^2 Al	0.07 cm^2 sterad.	3 mev $\leqslant E_p \leqslant$ 8 mev
Cylindrical scintillator NaI( )	0.18 g/cm^2 Al	6.8 cm^2 (isotr.)	at direct passage $E_e >$ 600 kev $K_p >$ 10 mev
GAS DISCHARGE COUNT.			
STS - 5	* 0.15 g/cm^2	4.3 cm^2 (isotr.)	$E_p >$ 9 mev $E_e >$ 500 kev
Si-3BG I	* 0.84 g/cm^2	0.1 cm^2 (isotr.)	$E_e >$ 2 mev $E_p >$ 25 mev
Si-3BG II	3 g/cm^2	0.1 cm^2 (isotr.)	$E_e >$ 7 mev, $E_p >$ 45 mev
END-WINDOW GAS DISCHARGE COUNT.			
SBT-9 No. 1	** 1 mg/cm^2	0.1 cm^2 sterad.	$E_e >$ 25 kev, $E_p >$ 0.5 mev
SBT-9 No. 2	*** 1 mg/cm^2	0.1 cm^2 sterad.	$E_e >$ 120 kev, $E_p >$ 0.5 mev
SBT-9 No. 3	**** 20 mg/cm^2	0.1 cm^2 sterad.	$E_e >$ 120 kev, $E_p >$ 3 mev

[Explanations] : * means Al plus steel
** - mica
*** - mica plus magnetic shield
**** - mica plus magnetic shield plus Al.

The semiconductor "P-r" counters were graduated by α- particles of polonium and uranium. At the sane time the amplitudes of pulses were measured at amplifier output and so were the radiotechnical thresholds of the discriminators. Comparison of calibrated data, obtained by such a method, with the graduation in protons provides the error in the estimate of the energy thresholds of no more than 10%. When irradiating the counters by a directed flux of electrons of $\sim 10^7 \frac{1}{cm^2 \ sec}$ with energy of 45 kev, a count of ~ 2 pulse/sec, caused by appliance of pulses from electrons, was registered. The radiotechnical circuit of counters assures the registration of proton fluxes to $7 \cdot 10^5 \frac{1}{cm^2 \ sec \ ster}$ with an error on counting of no more than 10%, while the overload characteristics, taken down, provided the possibility of determining unambiguously proton fluxes through $10^7 \frac{1}{cm^2 \ sec \ ster}$ by the count of semiconductor "P-r" counters.

RESULTS

Presented below are the results of data processing on measurement of low energy protons by semiconductor "P-r" counters during the period from the end of August to the end of December 1964.

The intensity variation of protons with energy from 0.4 to 7 mev plotted by curves for the 3, 19, 21 September, 9 October and 19 December 1964, alongside with the intensities of the magnetic field B (curves 1) are plotted in Fig. 1., where the height of the satellite above the Earth, h is also represented (curve 2) as a function of the parameter L [1]. For the curves for the 3rd, 19th, 21st September and 9th October, the intensity of the magnetic field B is given by solid curve 1. Over this portion of satellite trajectory the angle between the axis of the "P-r" counter and the magnetic lines of force constitutes $\sim 60^\circ$; therefore counters registered protons with pitch-angles lying in the angle interval from 30° to 90°. For the curve for 19 December, the intensity of the magnetic field is given by the dashed curve 1, while the angle between the magnetic lines of force and the axis of counters was in this case of $\sim 40^\circ$. The increase in the magnetic field intensity and the decrease of pitch-angles had conditioned the lowering of proton intensity registered on 19 December.

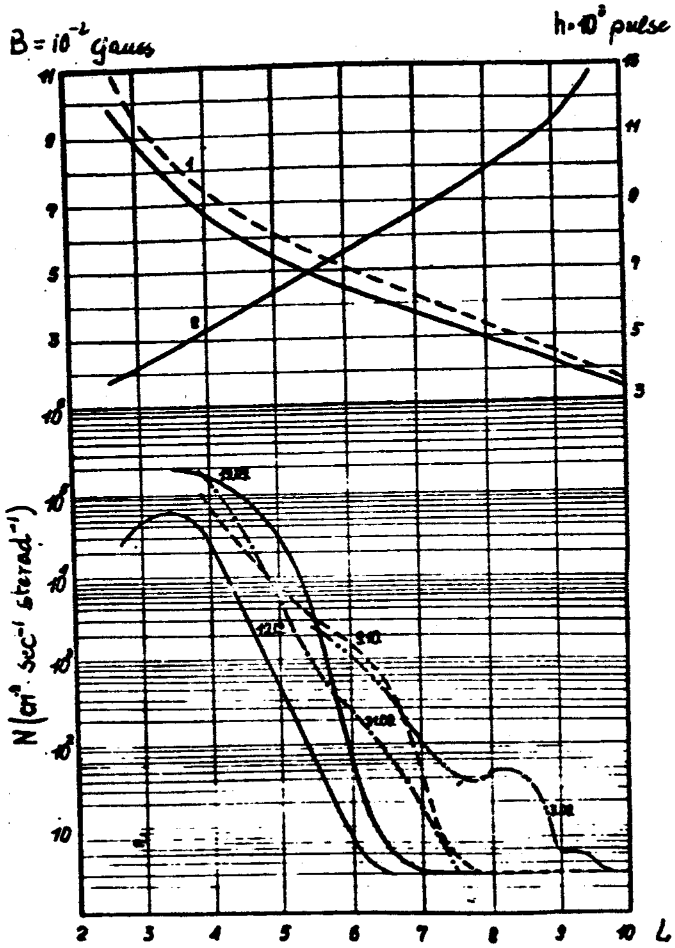


Fig. 1

The count of the second "P-r" counter, registering photons with energy of 3 — 8 mev, at L from 3.5 to 10 at indicated values of B, for the period from the end of August to the end of December 1964, was always below or at the level of measurement limit, that is $\sim 3 \frac{1}{cm^2 \text{ sec ster}}$.

Therefore, it may be seen from Fig. 1 that on $L = 3.5$, the measured intensity of protons with energy of 0.4 to 3 Mev attained

$$2 \cdot 10^5 \frac{1}{cm^2 \text{ sec sterad}}.$$

If we represent the inclination of proton intensity drop as a function of L by the expression L^{-n}, then, for the steepest drop of proton intensity (19 August), n is obtained equal to 30.

Aside from the information from the above-indicated portions of satellite trajectory, there are data from the descending portion of the trajectory in the region of the geomagnetic equator. In this case the satellite shifted nearly along the magnetic line of force, and the axis of "P-r" counters constitute an angle of 30° with the magnetic line of force. Therefore the intensity of protons on the same was the one registered, but at substantially different values of the parameter B; at the same time, the difference in measurement time at high latitudes and in the equatorial region constituted less than 8 hours. Data on such measurements for 1 September 1964 on $L = 5$ at points A and B of satellite trajectory are compiled in Table 2.

If we admit that the distribution of protons by pitch-angles in the equatorial region satisfies the expression $P = \sin^{\alpha+1}\theta$, where $\alpha = 2$ (this agrees well with the experimental data of [2]), then, for normalizing the intensity at the point B is is necessary to introduce the factor of 6, and the ratio of intensities $\frac{N_p(B)}{N_p(A)}$ will become equal to 18. Hence, by representing the altitude course as $(B/B_{equ})^{-k}$, we obtain that $K \simeq 1$.

TABLE 2

$L = 5$

A	B
$h = 6.6$ th. km. $\Lambda = 49^o$ No.lat. $B = 5.4 \cdot 10^{-2}$ gauss $\theta = 60^o$ $N_p = 10^4 \frac{1}{cm^2 \text{ sec ster}}$	$h = 26$ th. km. $\Lambda = 0$ $B = 0.25 \cdot 10^{-2}$ gauss $\theta = 30^o$ $N_p = 3 \cdot 10^4 \frac{1}{cm^2 \text{ sec ster}}$

N. B. h is the height above the Earth's surface;

Λ is the geomagnetic latitude;

B is the intensity of the magnetic field;

θ is the angle between the axis of "P-r" counters and the magnetic line of force;

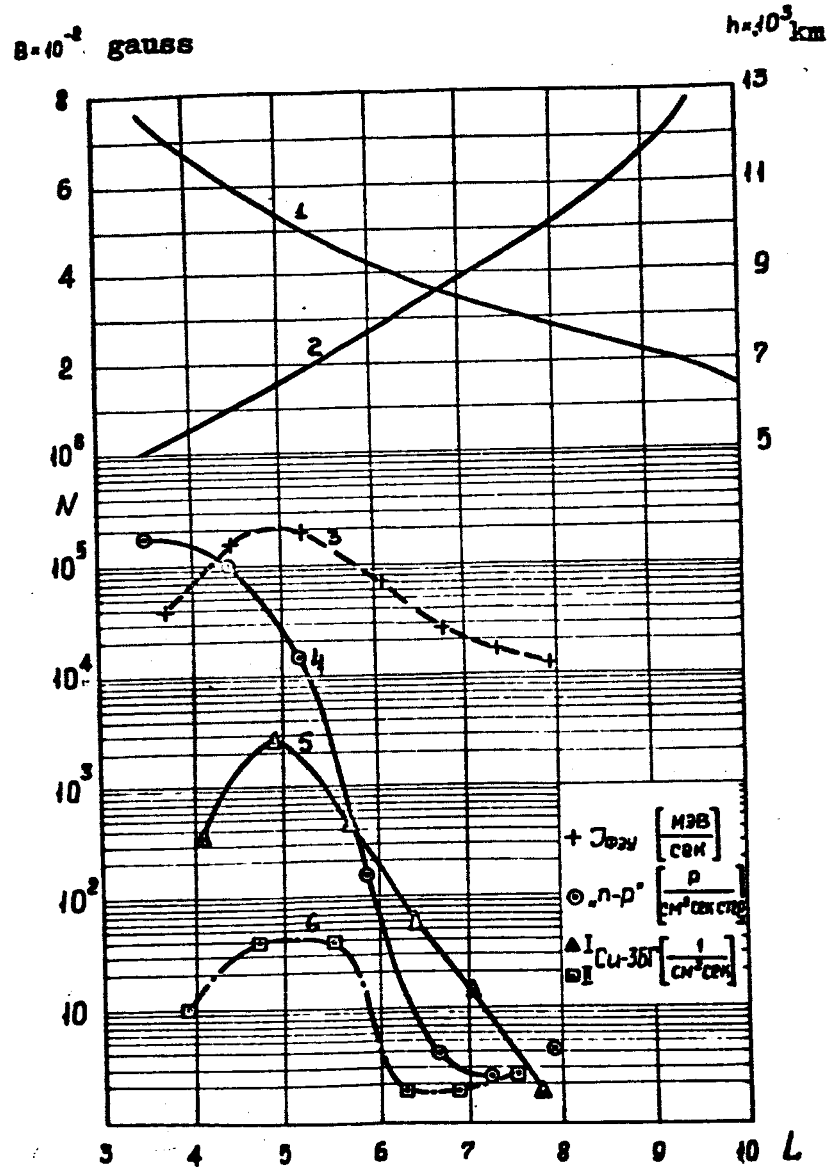
N_p is the intensity of protons with energy 0.4 – 3 Mev

If we assume that such a course for protons of above-indicated energy is also valid for lower L, then on $L = 3.5$ in the geomagnetic equator, our detector could have registered a proton flux of

$$6 \cdot 10^6 \frac{1}{cm^2 \text{ sec sterad}}.$$

As is shown in [2], the proton spectrum of the outer belt can be approximated by the expression $\exp(-E/E_0)$. By measurements on $L = 5$ and $\Lambda = 0$, it is possible to determine that $E_0 \leqslant 280$ kev.

Data on the registration of electrons of the outer radiation belt for 19 September 1964are represented in Fig. 2 in the same form as in Fig. 1. The curves 5 and 6 represent the counting rates of the gas-discharge counters Si-3BG Ii, differing only by the shielding, and the curve 3 shows the variation of the mean anode current of the photomultiplier with a NaI (1) crystal, expressed in mev/sec.



$+ I_{FEU}$ $\frac{mev}{sec}$

"P-r" $\frac{p}{cm^2 sec\ ster}$

Si - 3BG $\frac{1}{cm^2 sec}$

Fig. 2

Contribution could be made to scintillation detector current by protons with enery $E_p > 10$ mev, electrons with energy $E_e > 600$ kev by direct passing into the crystal and by electrons of lower energy at the expense of bremmstrahlung.. For comparison we plotted in Fig. 2 the curve of detector counting rate of protons with energy 0.4 – 7 mev (curve 1). From the course of the curves it may be seen that the intensity maximum of electrons of the outer radiation belt is registered on L = 5. Moreover, a steeper drop with the rise of L of the counting rate of gas-discharge counters, registering the energetic electrons, by comparison with photomultiplier current, characterises the fact, that the spectrum of outer belt electrons shifts with the increase of L to the region of lower energies. It should be noted, that the intensity ratio of electrons, registered over trajectory A and B portions at $L = 5$ by gas-discharge counters is 20. (No normalisation is required in this case, since the character of radiation registration by gas-discharge counters of the indicated type is nearly isotropic).

The processing of data according to other stallite passages at the same geomagnetic latitudes and distances from Earth shows, that the variations of the configuration and intensity of the outer part of the proton belt are, as a rule, linked with the variations of outer radiation belt electrons.

In the lower part of Fig. 3 we plotted by dots the intensities of protons, registered in the same region of space as for Fig. 1, and in the upper part we plotted the intensities of electrons of the outer radiation belt according to data of the gas-discharge counters for the period of time from 28 August to 10 October 1964. For clarity, we brought out the curves of electron and proton intensities for the 4th and 19th September, all this for different values of L.

It may be noted, that the greatest variations in the intensity of electrons for a fixed L take place in the region $L = 5 \div 7$; at the same time, change in the position of the maximum as well as in the intensity of electrons in the maximum takes place, whereas for the intensity of protons, variations increase with the rise of L through $L = 10$, while the position of the maximum remains invariable, or nearly so.

Shown in Fig. 4 are the variations in the intensity of low energy protons for various L– envelopes according to measurements for the periods from 31 August to 4 September and from 16 to 21 September, and of electrons registered by the gas-discharge counters types Si- BG and STS-5. In the lower part of the drawing the variations of the three-hour K-index for the above-indicate time periods [3]. From the examination of the graphs it may be seen that there is an obvious positive correlation in the temporal variations of proton and electron intensity, this correlation being

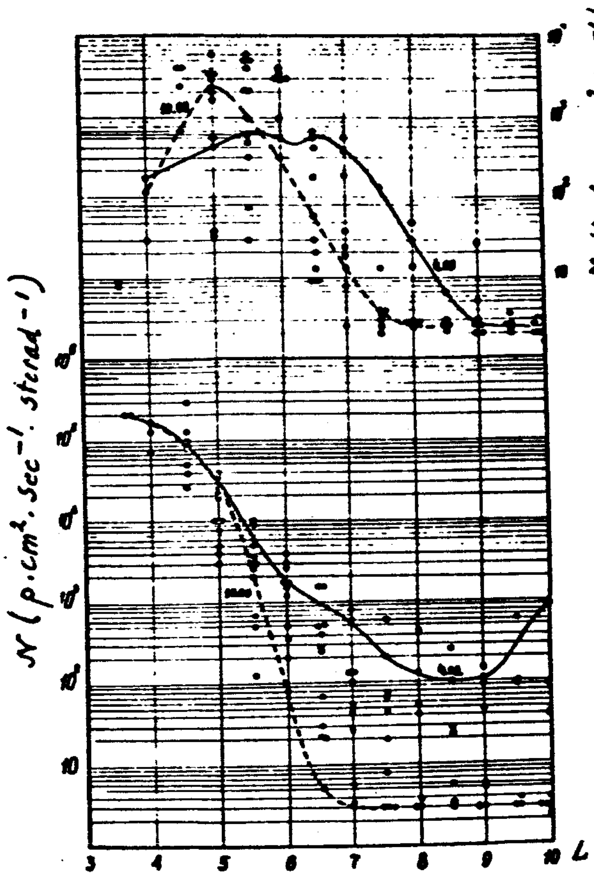


Fig. 3

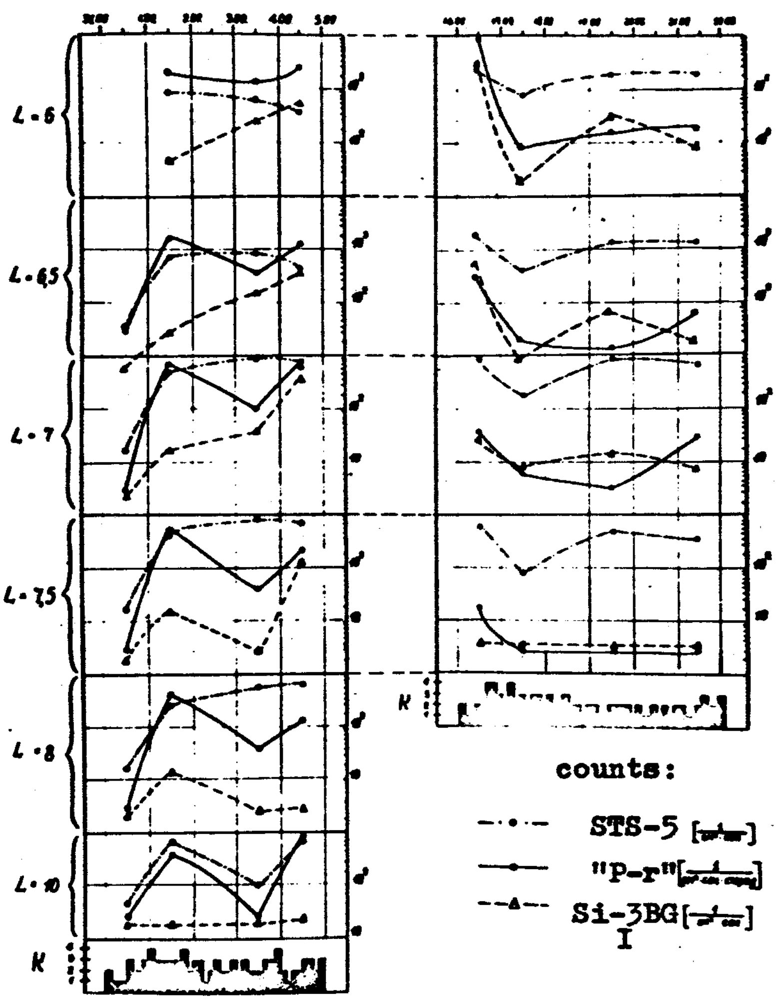


Fig. 4

stronger for a more energetic component of electron radiation. Only for L = 10 is the opposite pattern observed, but it may be seen from Fig. 3 that for L = 0, the count of the Si-3BG counter was at cosmic radiation background level during the entire duration of the experiment. Besides, it is visible from Fig. 4, that the appearance of significant intensity of protons and electrons in the L-region between 7 and 10, is linked with the increase of magnetic disturbances.

Therefore, it may be assumed, that protons of solar origin, having passed through the shock wave at magnetosphere boundary, undergo a subsequent drift, with acceleration across L – sheaths as a result of nonstationary magnetic disturbances. The energetic electrons, having hit the magnetosphere, are apparently subject to the same mechanism [4].

In certain cases for great L, the semiconductor detector fixed a sharp increase in the flux of low energy protons. Curve 3 of Fig. 5 represents the peak of proton intensity, registered on 29 September 1964, for $L = 9.5$; at the same time, it is seen that by comparison with the usual intensity of protons in this region of space (curve 4 for 31 August), the intensity increased by three orders. The count of the scintillation detector with a threshold of response of 90 kev (curve 1) for 20 September was somewhat higher than usual (curve 2), and in the region of the proton peak it increased by a factor of 3. The Si – ZBG I and II (curves 5 and 6) revealed no variations and their count coincided with the usual one. Beginning with 00 oo hrs UT on 28 September and to 0300h on 29 Sept., the ground station recorded a small storm with gradual commencement, whereas the K-index of 28 – 29 September doubled, as an average, reaching the value of 5 [3].

Presented also in Fig. 1 are the anomalous events taking place on the outer boundary of the protonosphere (curve for 3 September). Here the smoothest peak of proton intensity was observed on $L \simeq 8.5$.

In the context of the geomagnetic conditions, the case ressembled a great deal the preceding one. Beginning with 22 00 hours UT on 31 August and to 05 00 hrs on 2 September, a small storm with gradual commencement was observed with the increase of K -index. The data are plotted in Fig. 4 and they point to the fact, that on 1 September an increased intensity of protons ($10^3 \div 5 \cdot 10^2 \frac{1}{cm^2 \text{ sec sterad}}$) was registered everywhere in the region of L variation from 7 to 10. At the same time, the intensity of electrons also rose sharply by comparison with the measurements of 31 August. By 3 September the intensity of protons lowered substantially in the given region of space, forming the above-indicated peak, and on 4 Sept. it increased again, with a maximum at $L \simeq 10$.

* * *

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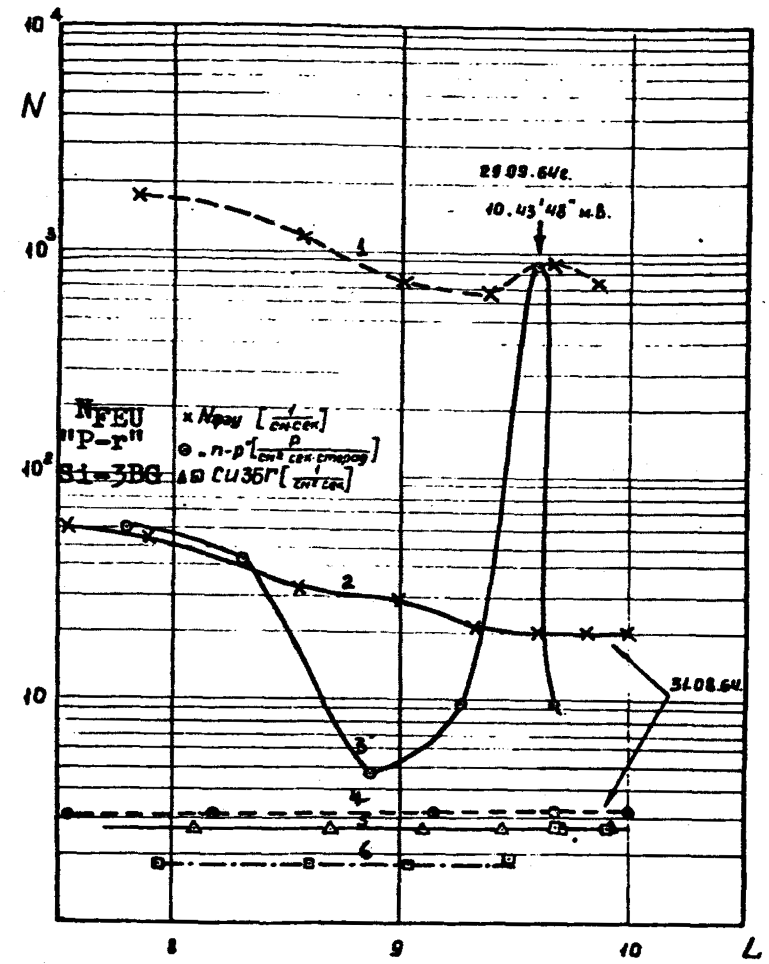

Fig. 5

CONCLUSIONS

From the results of measurements of protons with energy from 0.4 to 7 mev and of electrons of the outer radiation belt, we may derive the following conclusions :

a) the outer proton belt constitutes a relatively steady formation and temporal variations mainly affect the outer part of it, beginning with $L \gg 4.5$;

b) the presence of identical altitude course and the character of variations of low energy protons and hard electrons of the outer belt at $L \gg 5$ point to a common trapping and acceleration mechanisms for both forms of radiation;

c) taking into account the dependence of these variations on the geomagnetic conditions, one may assume, that the anomalous diffusion is such a mechanism [4]; this anomalous diffusion of particles in the Earth's magnetosphere on account of weak stationary disturbances of the geomagnetic field is indeed observed rather frequently.

In conclusion the authors extend their thanks to B. V. Tverskoy for his interest in the work and to all laboratory co-workers having participated in the conducting of the experiment.

**** THE END ****

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on 30 — 31 May 1965

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[NOTE FROM TRANSLATOR]

Due to the fact that this translation is made from a rough preprint containing several long-hand corrections in Russian and many questionable latin capital letters, some errors of interpretation may eventually be found in this rough translation.-

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